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Landfills sizing in metropolitan areas

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Abstract

Waste managers have often to decide whether to undertake an irreversible one-shot capital outlay and invest in a potentially over-sized facility or to proceed with sequential investments to adapt to changes and reduce potential losses. In this paper, we determine the value of managerial flexibility to decide the capacity sizing of a landfill according to the Real Option Approach. We model the investment decision as the exercise of a compound option, where an earlier investment cost represents the exercise price required to acquire the subsequent option to continue operating the project until the next stage comes due.

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Keywords: Landfill; investment decisions; growth options; sequential investments; uncertainty.

1. Introduction

Metropolitan areas due to high urbanization and high population density are facing an alarming rise in solid waste production that shorten the length of landfill life. Population growth and dense urbanization result in receding landfill space that in turn represent a major issue for policy makers and local administrators. The limited number of agents, both public or private, able to meet the solid waste management demands, compete for financial resources to extend landfill life or obtain permits to invest in new infrastructure. There are many contributions in the literature that address theoretical waste management facility expansion and waste flow allocation within a solid waste management system under uncertainty (Huang, Baetz, & Patry, 1995; Davila, Chang, & Diwakaruni, 2005).

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At the same time due to the scarcity of land and the environmental and social costs of landfilling such as. emissions to air, soil and water or 'disamenities' such as odours (Eshet et al. 2006; Nahman, 2011), during the last 30 years municipal waste management focused on the objective to divert as much waste as possible from landfill. The literature on the choice among different waste management solutions is vast and has provided a consistent set of arguments in favor of a policy targeted at reducing waste flows addressed to landfill and recovering materials and energy (Pires, Martinho, & Chang, 2011; Massarutto, de Carli, & Graffi, 2011; Marella & Raga, 2014).

Starting from the 1990s the EU introduced compelling regulations on the construction and operation of landfills in order to promote recycling to better comply with sustainability constraints on land conservation and achieve environmental policy targets set by the EU (Kinnaman, 2006; EEA, 2009). In many Countries Governments have issued directives to minimize the amount of waste sent to landfills, nevertheless, it is impossible to eliminate the need for landfills because some materials are impossible to recycle (Diaz & Warith, 2006). In this respect the EU 2008/97 directive sets the objective to minimize landfill requirement, that should be used only for ultimate waste (waste that cannot be recovered in any way). Although landfilling had strongly reduced in the past decades in favor of recycling programs, a complete phase-out of diverting waste flows from landfills has not been achieved yet. Italy, United Kingdom, France and Spain are still landfilling around 40-50% of their solid waste (Antonioli & Massarutto, 2012; Massarutto, de Carli, & Graffi, 2011). It is therefore evident that landfilling represents a critical issue for policy makers and local administrators level because of the self-sufficiency principle (i.e. waste should be handled as close as possible to its origin to prevent from transport costs and related external costs).

Usually municipalities delegate solid waste treatment and disposal to third parties and have long-term contracts (i.e. procurement or concession contracts) with private firms that operate as regional or local monopolists and have, as a counterpart, to fulfill public service obligations and the legal obligation to receive waste from the concerned territory at regulated prices. It is commonly agreed that the provision of the service and related investments are characterized by great uncertainties. Uncertainty over future demand due to recycling programs and incineration, increasing operating costs and tightening up of regulatory requirements make de facto investment decisions more crucial than ever (Teisberg, 1993; Teisberg, 1994). In this evolving scenario, waste managers have often to decide whether to undertake an irreversible one-shot capital outlay and invest in a potentially over-sized facility or to proceed with sequential investments to adapt to changes and reduce potential losses.

Traditional Discounted Cash Flows techniques may be inadequate to cope with dynamic decisions and clearly underestimate the value of compound investments (Trigeorgis, 1996; Gamba & Fusari 2009; D'Alpaos *et al*., 2013; D'Alpaos & Marella, 2014). It is widely recognized that Discounted Cash Flow Analysis fails because it cannot properly capture managerial flexibility to adapt and revise later decisions in response to unexpected market events (Triantis & Hodder, 1990; He & Pindyck, 1992). Indeed, the importance of this flexibility becomes of paramount importance when market conditions are volatile and technology is flexible, thus permitting managerial intervention at limited cost (Dixit & Pindyck, 1994; D'Alpaos & Moretto, 2005; D'Alpaos, Dosi, & Moretto, 2006). In a framework of economic action under uncertainty and irreversibility (or costly reversibility), waiting for new information that reduce uncertainty may affect the investment profitability (Brennan & Schwartz, 1985; McDonald & Siegel, 1986).

In this paper, we determine the value of managerial flexibility to decide the capacity sizing of a landfill according to the Real Option Approach. We model the investment decision as the exercise of a compound option, where an earlier investment cost represents the exercise price required to acquire the subsequent option to continue operating the project until the next stage comes due.

The remainder of the paper is organized as follows. In Section 2 we provide the basic model and we derive the optimal investment strategy. In Section 3 we present a stylized case study and provides numerical simulations to illustrate the model's theoretical results. Section 4 concludes.

2. The model

Landfill design and construction technology have rapidly advanced during the past two decades in response to more stringent regulatory constraints on the one hand, and to highly variable waste generation and demand on the other. It is quite common to design solid waste landfill facilities which can be expanded by sequential investments over time. Landfill construction is in fact constrained to a phased programming and usually consists of construction of new units or cells or lateral expansion of existing ones. Undertaking the first phase (e.g. starting construction by excavation) is a prerequisite for the next (e.g. adjoining new cells). In other words the first investment provides the opportunity to acquire at maturity the benefits of the subsequent investment by making a new capital outlay.

In this section we provide a basic model to determine the optimal investment strategy of a service provider who has the opportunity to proceed with sequential investments in the construction and operation of landfill facilities.

Starting from D'Alpaos & Moretto (2005), we extend the benchmark case of a provider that committed to a single indivisible investment (e.g. the construction of a landfill of assigned size) by assuming that the investor has the possibility of choosing between two alternative projects *A* and *B* of different scales.

Investment *A* and investment *B* are large-scale projects (i.e. landfills)[†], and once installed they generate instantaneous net cash flows $\Pi^A_t(X^A)=\pi_t X^A$ and $\Pi^B_t(X^B)=\pi_t X^B$ respectively, where X^A and X^B are the maximum storage capacities (in tons) and π_t is the instantaneous profit per ton. The instantaneous net revenue (i.e. profit) can be described under risk-neutral probabilities (Cox & Ross, 1976) by the following Geometric Brownian Motion (GBM):

$$d\pi_t = (r - \delta)\pi_t dt + \sigma \pi_t dz_t \qquad \pi_0 = \pi\,(t=0) \tag{1}$$

where r is the instantaneous risk-free rate of return, $\delta>0$ is the rate of return shortfall (that represents the opportunity cost of waiting to invest), r-$\delta\geq 0$ is the cost of carry, and $\sigma>0$ is the instantaneous volatility.

In the specific, π_t is the difference between the tariff and the operating and managerial costs for the setting up and operation of the site, closure and after-care for at least 30 years, as specified by the EC Council Directive 1999/31, article 10. Tariffs are calculated according to the full cost recovery principle and the unit profit is to some extent the difference between the gate fee paid to the service provider and the costs for operation and management of the landfill, including restoration and aftercare costs. Investment costs include acquisition costs, capital expenditure, development costs and equipment costs, insurance costs, safety costs, etc.

Investments *A* and *B* are sequential, with *A* occurring before *B*, and entail sunk capital costs I^A and I^B respectively. In other words, the service provider can always invest in *A* and subsequently invest in *B*, incorporating the former into the latter, and consequently I^B represents the cost of upgrading *A* to *B* plus the cost of incorporating *A* in *B*.

Alternatively, the service provider can proceed directly to the one-shot investment *L* of size *X* where $X=X^A+X^B$, and incur the irreversible cost *I*. For the sake of simplicity, we assume that for both the sequential and the one-shot investments the opportunity to invest is not subject to time constraints.

Given the above assumptions, for any $t\geq 0$ $V^B(\pi_t)=\gamma\pi_t X^B$ is the value of project *B*, where $\gamma\pi_t X^B$ is the discounted value of future cash flows generated by *B* and γ is a scale factor that accounts for average future reduction in the profit due to waste stream variations over time discounted at time *t*[‡]. Whereas the opportunity to invest in project *A* embeds the option to switch at a future date to project *B*. It is reasonable to assume that the provider switches to project *B* once the maximum storage capacity X^A has been reached. Under this assumption, the optimal investment strategy is to switch from *A* to *B* as soon as π_t exceeds the critical threshold π^*_{AB}:

$$\pi^*_{AB} = \frac{\alpha}{\alpha - 1} \frac{I^B}{(\gamma X^B)} \tag{2}$$

[†] As an example, investment *A* can be a landfill and *B* represents an expansion of the previous one or another landfill built in adjacency. *A* and *B* can also be sectors of the same landfill. In this latter case *A* and *B* have usually the same size.

[‡] $\int_t^T x_b\, e^{-r(s-t)} dt = \frac{(T-t)x_b}{r}\left(\frac{1-e^{-r(T-t)}}{T-t}\right) = X_B\left(\frac{1-e^{-rT}}{rT}\right) = \gamma X_B$, where x_b the time unit stream of waste and $X_b=x_b(T-t)$.

where $\alpha = \frac{1}{2} - \frac{r-\delta}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{r-\delta}{\sigma^2}\right)^2 + \frac{2r}{\sigma^2}} > 1$.

Consequently, the present value of project *A* is :

$$V^A(\pi_0) = \pi_0 X^A + \left(\frac{\pi_0}{\pi^*_{AB}}\right)^{\alpha} \frac{I^B}{(\alpha\text{-}1)} \tag{3}$$

where the first term $\pi_0 X^A$ is the discounted value of the future cash flow generated by *A* and the second term identifies the growth option embedded in *A*.

The threshold π^*_A that triggers investment in project *A* is:

$$\pi^*_A = \frac{\alpha}{\alpha\text{-}1} \frac{I^A}{X^A}. \tag{4}$$

When $\pi^*_A < \pi^*_{AB}$ it is optimal to proceed by sequential investments, i.e. it is optimal to invest firstly in project *A* and then wait to invest in project *B* until the instantaneous profit π_t exceeds π^*_{AB}.

If the service provider decides to commit to the one-shot investment *L*, the threshold that triggers the investment is:

$$\pi^* = \frac{\alpha}{\alpha\text{-}1} \frac{I}{X}. \tag{5}$$

According to (*4*) and (*5*), when $\pi^* \leq \pi^*_A$ the optimal investment strategy is to invest in *L* and not to proceed by sequential investments. Whereas, when $\pi^*_A \leq \pi^*$ it is always optimal to proceed by sequential investments.

It is worth note that the thresholds π^*_A, π^*_{AB} and π^* depends on the volatility σ, the opportunity cost of waiting to invest δ, the maximum storage capacity and the investment costs. According to the dependency of the triggers by α, *ceteris paribus*, the greater σ, the greater the option to defer investments; the greater δ the smaller the option to defer (i.e. investment accelerates). Due to the triggers dependency on costs, the optimal investment strategy is highly sensitive to the presence of economies or diseconomies of scale. When investment costs exhibit economies of scale and $X^B = X^A$, it is always optimal to invest in the one-shot investment; otherwise the optimal investment strategy is to proceed by sequential investments. In this latter case, the switching time is sensitive to both the investment costs (sum of upgrading costs and costs of incorporating *A* in *B*) and the scale factor. *Ceteris paribus*, the smaller the scale factor, the higher the threshold that triggers the next stage of investment and consequently the longer the switching time; vice versa, the greater the scale factor, the shorter the switching time and the more investment accelerates.

3. Numerical example

In this section we present a stylized case study and provide some numerical simulations to illustrate the model theoretical results. We refer to the Italian setting and consider the case where the service provider has the opportunity to invest in a landfill facility. Project *A* and *B* are sanitary landfills for non-hazardous waste, specifically for municipal solid waste. The landfills geometrical configuration consists of an "above and below ground fill" (Quian, Koerner, & Gray, 2002) and the waste disposal is in line with the site topography according to international best practices. Costs, revenues and other variables were estimated through direct interviews with industry experts and waste mangers and through a survey conducted on a sample Italian sanitary landfills. The scarcity rent, that depends on the physical shortage of these facilities (Massarutto, 2007), was added to the pure industrial cost, and it was assumed to be actually shared between local authorities (royalties and compensative payments), regional authorities (landfill tax) and site owners. Landfill *A* and *B* have maximum storage capacities equal to X^A=300,000 tons and X^B=300,000 tons respectively and the investment costs are equal to I^A=6,000,000 Euros and I^B=6,600,000 Euros. Landfill *L* maximum capacity is *X*=600,000 tons. In order to show the effects of diseconomies/economies of scale on the investment strategy, we assume that investment costs are *I*=12,500,000 Euros and *I*=11,500,000 Euros respectively. According to our estimates, unit revenues *R* are equal to 45.5 Euros per ton, unit operating and managerial costs *C* are equal to 87 Euros per ton, and therefore the current profit π_0 is equal to 41.5 Euros per ton. According to projections by industry experts γ is equal to 0.9. The risk-free rate of return is *r*=3%: it coincides with the average interest rate on Italian Treasury Bonds (BTPs) with a maturity comparable to the project's life.

We performed numerical simulations for different values of volatility and cost of carry to test the model's theoretical predictions. The calibration parameters follow as close as possible indications in related studies (Dixit & Pindyck, 1994; Trigeorgis, 1996). Tables 1 displays the optimal thresholds that trigger the investment for γ=0.9, *r*=3%, δ=1%, 2%, 3% and σ=10%, 20%, 30%. The results show that when $X^A=X^B$, and in the presence of economies of scale (i.e. I=11,500,000 Euros), the optimal investment strategy is to undertake the one-shot investment. Whereas *ceteris paribus*, in the presence of diseconomies of scale (i.e. I=12,500,000 Euros), the optimal investment strategy is to proceed by sequential investments. In other words in this latter case, it is always optimal to invest in *A* and wait to invest in *B* until the critical threshold is reached. Moreover when $\pi_0<\pi^*_A$, there is a positive option value to delay the decision to invest in project *A* regardless the Net Present Value of project *A* is positive. By optimally exercising this investment timing flexibility, the service provider can increase the investment Net Present Value by the value of flexibility. When $\pi_0\geq\pi^*_A$ it is always optimal to invest immediately, i.e. the option value to wait to undertake the first project is null. Ceteris paribus as δ increases the investment thresholds π^*_A, π^* and π^*_{AB} decrease and both the optimal investment timing and switching time reduce and investments accelerate. Whereas as σ increases, these thresholds increase and it is more valuable to wait for more information to come before undertaking the investments. When the triggers are lower than the current profit, it is never profitable to postpone investments: it is optimal to invest immediately and the traditional Net Present Value rule holds. In particular when *I*=12,500,000 Euros, δ=2% and σ=10% it is optimal to proceed by sequential investments, whereas when *I*=11,500,000 Euros, δ=2% and σ=10% is optimal to proceed by sequential investments. Furthermore independently from *I*, when, δ=3% and σ=10% it is optimal to invest immediately in the greater scale project *L*.

Table 1. Optimal triggers (in Euros) for C=87 Euros/ton, R=45.5 Euros/ton, π_0=41.5 Euros/ton, *r*=3%, γ=0.9 and different values of σ and δ.

r=3%	*I*=12,500,000 (Euros)			*I*=11,500,000 (Euros)		
	σ			σ		
	10%	20%	30%	10%	20%	30%
δ=1%	π^*_{AB}=90.11 π^*_A=73.72 π^*=76.79	π^*_{AB}=133.21 π^*_A=108.99 π^*=113.53	π^*_{AB}=198.76 π^*_A=162.62 π^*=169.39	π^*_{AB}=90.11 π^*_A=73.72 π^*=70.65	π^*_{AB}=133.21 π^*_A=108.99 π^*=104.45	π^*_{AB}=198.76 π^*_A=162.62 π^*=155.85
δ=2%	π^*_{AB}=48.89 π^*_A=40.00 π^*=41.67	π^*_{AB}=73.33 π^*_A=60.00 π^*=62.50	π^*_{AB}=107.79 π^*_A=88.19 π^*=91.87	π^*_{AB}=48.89 π^*_A=40.00 π^*=38.33	π^*_{AB}=73.33 π^*_A=60.00 π^*=57.50	π^*_{AB}=107.79 π^*_A=88.19 π^*=84.52
δ=3%	π^*_{AB}=36.67 π^*_A=30.00 π^*=31.25	π^*_{AB}=54.15 π^*_A=44.31 π^*=46.15	π^*_{AB}=77.88 π^*_A=63.72 π^*=66.38	π^*_{AB}=36.67 π^*_A=30.00 π^*=28.75	π^*_{AB}=54.15 π^*_A=44.31 π^*=42.46	π^*_{AB}=77.88 π^*_A=63.72 π^*=61.07

4. Conclusion

Uncertainty over future demand, increasing operating costs and regulation make operational decisions in landfill construction and management more crucial than ever. In this paper we model the investment strategy of a landfill manager who has discretion to proceed by sequential investments in landfill construction. We then performed numerical simulations on a stylized case study to illustrate the theoretical model's predictions. Results show that the investment decision whether to proceed by sequential investments (*A* and *B* respectively) or to invest in the one-shot investment (*L*) is sensitive to the opportunity cost of waiting to invest and to uncertainties over future net revenues.

The investment decision is conditional to the trade-off between the option value of waiting for new information to come and the opportunity cost of waiting. Finally it is worth to remark that, *ceteris paribus*, in the presence of economies of scale, the optimal investment strategy is to commit to the one-shot investment. Whereas, when investment costs exhibit diseconomies of scale, it is always profitable to proceed by sequential investments: i.e. it is optimal to invest firstly in project *A* and waiting to invest in *B*, whenever the instantaneous profit reaches the critical threshold that triggers the switching.

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